Baltic J. Modern Computing, Vol. 13 (2025), No. 3, 680-693
https://doi.org/10.22364/bjmc.2025.13.3.07

M-Learning for Climate Resilience: A Case Study of Latvia's Indigenous Crop Initiative in Ghana

Maija KĀLE[1, 2], Marija KRŪMIŅA[2], Lily KELEDORME[3], Mary NUMAFO[3]

[1]Baltic International Centre for Economic Policy Studies (BICEPS), Strelnieku street 4a Riga, LV-1010, Latvia
[2]The Faculty of Science and Technology, University of Latvia, 19 Raina Blvd., Riga, LV-1586, Latvia
[3]Farmerline Group, 4th Alajo Ave, Accra, Ghana

maija.kale@lu.lv, marija@biceps.org, lily@farmerline.co, serwaa@farmerline.co

ORCID 0000-0002-6951-9009, ORCID 0009-0006-7890-6445, ORCID 0009-0008-0461-5658, ORCID 0009-0003-2507-0961

Abstract: The rapid evolution of digital technologies holds significant potential for transforming the acquisition of information and knowledge, particularly in regions such as sub-Saharan Africa (SSA), where mobile technologies are leading the growth of the tertiary sector. Mobile phone-based ICT-enabled learning (m-learning) is seen as a key tool for agricultural development, but research on its effectiveness in promoting sustainable agricultural practices in SSA remains limited. Despite the increasing implementation of m-learning initiatives by international donors, the academic literature linking these projects with research on their impact is sparse. This study examines the role of m-learning in improving agricultural livelihoods in SSA, focusing on the development cooperation project 'Building Digital Education of Indigenous/Heritage Crops for the Resilience of African Food Systems in the Climate Crisis' (ICRAFS), which uses a mobile-based education module delivered in multiple languages to rural farmers with limited internet access. The research examines critical factors influencing the success of m-learning, such as mobile phone ownership, gender inequalities and cognitive biases. Despite the promise of m-learning to bridge gaps in agricultural knowledge and climate resilience, challenges related to technology access, social norms and timing of content delivery need to be addressed. This study contributes to the research gap in mobile-based agricultural learning and provides insights for designing future m-learning initiatives to enhance sustainability and resilience during the climate crisis.

Keywords: food systems, climate change, development cooperation, m-learning, digitalisation

1. Introduction

The rapid evolution of digital technologies, often called the "fourth industrial revolution," is characterized by the integration of physical, digital, and biological systems sector

(Baumüller, 2018), offering significant potential for transforming the way we obtain the information and acquire knowledge. Mobile technologies, in particular, are seen as a key enabler for economic growth and poverty alleviation in regions like Africa (Baumüller, 2018). It may be hypothesised that a substantial corpus of research literature exists pertaining to the efficiency, formats and optimal practices of mobile phone-based, ICT-enabled learning in specific domains, such as agriculture on a global scale and in Sub-Saharan Africa (SSA), a region that has been identified as a leader in mobile phone technology usage. However, this hypothesis is not supported by the extant literature. SSA is an under-researched territory in terms of mobile-phone based learning (m-learning) for more sustainable agriculture practices. While a growing number of international donors are funding implementation activities that are based on m-learning opportunities, little academic research has been generated connecting these development cooperation projects with research endeavours.

As is the case in any under-researched area, there is also an absence of established terminology that would be widely accepted for use. ICT (information and communication technology) enabled learning is frequently termed m-learning, thereby highlighting the role of mobile phones as the technological basis for such a type of learning. M-services deliver electronic media content through mobile technologies and are an umbrella term that includes m-agri, m-commerce, m-banking and m-payments (Baumüller, 2018); (Krell et al., 2021), and increasingly also m-learning. Mobile services encompass a variety of forms, including Short Message Service (SMS), Unstructured Supplementary Service Data (USSD), mobile applications (apps) and helplines (Krell et al., 2021). In addition to the terms associated with m-learning, the same types of learning are also associated with digitalisation, digital agriculture extension services and other terms. Overall, the various learning formats enabled by different technologies can be categorised according to the platform (mobile versus desktop), the mode of multimedia utilised (audio, text, visual information), their length (micro or short-lectures) and purpose – weather information for agricultural purposes, behaviour (and culture) change and other.

The purpose and impact of m-learning are challenging subjects to research, with even fewer documented cases than various m-learning initiatives that can be found globally. Significant research gaps have been identified as a key factor undermining the effectiveness of m-learning. Current studies provide limited insight into which features of m-services drive meaningful outcomes and rarely examine critical factors like risk attitudes or trust, which influence farmers' adoption decisions. Furthermore, women, who often face greater barriers in decision-making, are underrepresented in research, and the impact of user characteristics such as education, income, or access to personal phones is seldom considered. Self-reported data dominate impact assessments, while comparative analyses of delivery channels like SMS and voice remain scarce. Additionally, the lack of systematic evaluation of the farming and social contexts where m-services are deployed limits the understanding of their real-world applicability and effectiveness (Baumüller, 2018); (Krell et al., 2021).

Notwithstanding the aforementioned research limitations, digital extension services and mobile-based learning have gained significant importance for agricultural communities, particularly in developing countries, where mobile phone usage and internet access have exhibited substantial growth, including low-income populations (Fabregas et al., 2023). The technologies in question have been shown to provide direct benefits, including communication and access to information. Furthermore, they have the potential to enhance economic development in the agricultural sector. Recent studies have

highlighted key impacts, including the improvement of earnings and the reduction of waste for farmers in various regions, as a result of mobile phone usage (Adenubi et al., 2021; Ndimbo et al., 2024). Research has indicated a positive correlation between mobile phone use in sub-Saharan Africa (SSA) and increased agricultural yields and profits. For instance, a study conducted in Tanzania revealed that 72% of the survey participants reported higher agricultural profits as a result of mobile phone usage. Moreover, 55% noted a reduction in costs incurred in farming activities (Quandt et al., 2020). Nevertheless, the efficacy of such services is contingent upon the level of engagement, as evidenced by recent studies. These studies demonstrated that farmers who participated in phone-based training programmes exhibited higher adoption rates of novel practices. Moreover, mobile technologies have been demonstrated to have a significant impact on market transparency, farm productivity and logistics. Indeed, there is ample evidence to suggest that they have increased farm-gate prices, facilitated improved input decisions and optimised supply chain management in a variety of global contexts (Kamal and Bablu, 2023). However, the realisation of these aforementioned benefits is significantly influenced by broader institutional factors. Such factors include, but are not limited to, political empowerment and income inequality (Fabregas et al., 2023).

It is evident that there is an absence of significant research in the domain of mobile-learning's impact, particularly concerning its influence on agricultural production in rural farming communities in the SSA region. A crucial question that merits academic attention pertains to the potential of m-services to enhance agricultural livelihoods in these communities. This issue is of particular relevance to scholars and development programmes that are dedicated to addressing the challenges faced by rural livelihoods (Krell et al., 2021). A further challenge for m-learning research is its focus on student populations rather than m-learning content receivers outside the walls of universities. Mobile devices have gained prominence in m-learning, but face numerous challenges, many of which remain under-researched and under-theorised. The findings of the present study of SSA demonstrate that 79% of reviewed papers targeted students, closely aligning with global trends where 78% of studies also focus on students. This observation suggests a congruence between SSA research trends in m-learning and global patterns (Kaisara and Bwalya, 2022). While research into the student target group is positive in itself, there is a lack of research into the outcomes of m-learning in real-life settings, where farmers face declining yields, deteriorating soil quality and the threat of climate change.

In general, rural agro-advisory services are undergoing a period of dynamic transformation across the globe. The integration of diverse information and communication technology (ICT) modules within rural advisory systems has already been demonstrated to be an effective mechanism in various regions worldwide, due to the comprehensive outreach of such initiatives. The significant advancements in mobile services have provided the necessary digital platforms for ICTs to reach even those farmers who are located in remote areas. Digital technology has created new avenues for policymakers and agricultural extension agencies to address historically excluded smallholder farmers, who have less contact with extension agencies and limited access to resources and extension services. Consequently, user-centric mobile phone applications have the potential to supplement and strengthen the accountability of the public agricultural extension system through real-time supervision at a relatively low cost and time (Lahiri et al., 2024). Although the advantages of outreach are evident, the methodological configuration that must be considered to ensure the efficacy of m-learning and the behavioural modification of the designated target audience remains less apparent.

The following discussion will proceed by examining m-learning developments as introduced here, and by taking a closer look at a development cooperation project titled "Building Digital Education of Indigenous/Heritage Crops for the Resilience of African Food Systems in the Climate Crisis" abbreviated as ICRAFS project. This project is supported by Latvia's Ministry of Foreign Affairs' development cooperation budget in 2024-2025. The objective of this project is to address the challenges of sustainable agriculture in the context of climate change by fostering a partnership between Latvia and Ghana. This partnership combines Latvia's expertise in preserving heritage (heirloom) crops with Ghanaian farming knowledge to create a scalable, digital education platform (BICEPS, 2024). The analysis will be conducted from the perspective of m-learning impact and efficiency. By analyzing the pilot educational m-learning module, consisting of 10 short audio lectures in six local languages, tailored for farmers with limited access to the internet or formal education, to be implemented in 2024. We aim to highlight and contribute to bridging this gap between development cooperation project implementation and research by providing a comprehensive research component to a project focused on transferring critical knowledge on indigenous crops and sustainable farming practices, reaching underserved communities in Northern Ghana, and promoting food system resilience through m-learning platforms.

2. Theoretical Basis

Mobile learning (m-learning) offers flexible, low-cost access to education and has been widely adopted by institutions, particularly in Africa. Despite its potential to address educational inequalities and align with the United Nations Sustainable Development Goal (SDG) 4 by promoting inclusive and lifelong learning, m-learning lacks global implementation models, particularly in resource-constrained contexts, and the challenges to m-learning adoption remain under-researched and under-theorised (Kaisara and Bwalya, 2022). Information and services delivered via mobile phones, 'm-services', have transformative potential to provide rural African farmers with critical agro-meteorological information. However, there is a need for a better understanding of the types of m-services available to farmers, how farmers access this information, and possible factors influencing the use of m-services (Krell et al., 2021). While this may seem like a feasible task, it should be recognised that these are not only contextual factors - such as the ownership of the mobile phone itself or the timing of the m-services (in our case the m-learning module) - but also various biases and issues related to the way in which m-learning takes place and the time span over which decisions are made in order to make m-learning efficient. In this chapter we will look at different factors that can theoretically affect the efficiency of m-learning.

One of the most critical factors in the effectiveness of m-learning, particularly in SSA, is the ownership of the mobile phone and thus the actual access to m-learning content. Ownership is not gender neutral, as men in SSA are much more likely to own a mobile phone than women, which means that m-learning has certain limitations when content is developed with women as the target audience. Smartphone ownership is an important factor in the use of m-services, as highlighted in a recent study from Kenya, where at the household level, men and women's roles on farms were different, and therefore the level of agricultural decision-making may vary depending on gender roles

when men are household heads. Although telephones have spread through rural communities, smartphones are the item that separates the richer from the poorer (Krell et al., 2021). The division is thus both gender and income related. Ownership of a mobile phone determines access to m-learning, while non-ownership involves additional relational aspects that need to be successful in order to actually access the m-learning content. For example, membership of informal farmer groups increased the likelihood of using m-services across all types of m-service use (Krell et al., 2021). This means that relational factors can play a role beyond the confines of the nuclear family, and informal and community-based groups can provide the necessary platform for m-learning that is not given on the basis of income and gender.

Other critical factors are cognitive factors, based on the format of how learning, including m-learning, actually takes place and leads to the intended behavioural change. A significant number of studies on environmental awareness have shown considerable promise from a number of perspectives. Indeed, they have shown a correlation with attitudes and behaviour. However, most government agencies have assumed that increased environmental awareness leads to positive environmental attitudes, which in turn lead to pro-environmental behaviour. However, people stop engaging in pro-environmental behaviour once the period of external reinforcement is over, or when the behaviour becomes inconvenient and financially unattractive (Wi and Chang, 2019). There is too little focus on m-learning content that addresses the short-, medium- and long-term financial benefits that would result from the behaviour change that m-learning invites. The main problem with most public environmental education initiatives is a disproportionate emphasis on the dissemination of information, with little emphasis on facilitating the understanding of the information provided (Wi and Chang, 2019). In the context of climate-related m-learning, this is not surprising, as behaviour change is rarely translated into immediate financial gains (otherwise the majority of global citizens would act in accordance with climate-smart behaviour). The consequences of climate change, including biodiversity loss, ecosystem disruption and reduced agricultural productivity, are becoming increasingly evident. However, addressing this global issue is challenging due to its 'social dilemma' nature. Sustainable actions often involve high individual costs while providing collective benefits, which can lead individuals to prioritise personal interests and rely on others to take action, rather than making a meaningful contribution themselves (Galeotti et al., 2024). This poses challenges to m-learning content, as complexity of information, accompanied by long time-lines and imaginary future gains, brings in a totally different modus operandi of learning than m-based weather forecasts sharing. How to transfer values and norms via m-learning platforms, remains an open question, just like for any other learning platform that is challenged with endeavours to shift behaviours to generate public good in long-term.

Motivating individuals to adopt pro-environmental behaviours in response to climate change is a complex challenge influenced by psychological factors such as decision-making self-efficacy - the belief in one's ability to act effectively. High self-efficacy increases the ability of individuals to translate fear of climate impacts into meaningful action. The Extended Parallel Process Model (EPPM), rooted in appraisal theory, highlights the interplay between perceived threat (severity and vulnerability) and efficacy (response and confidence) in shaping behaviour. While widely used in health communication, the potential of EPPM in climate risk communication remains underexplored. Understanding how individuals assess risk and build confidence to act is critical for designing interventions that promote sustainable pro-environmental behaviour

(Shah et al., 2021). While m-learning has been praised for its accessibility component, the ability to reach remote communities in a language they understand is only one of the issues at stake. Much more difficult is the use of m-learning platforms to determine levels of self-efficacy and confidence that individual actions have an impact on collective processes. However, these aspects could prove to be the most crucial for the success of the implementation of m-learning modules.

This leads to a broader discussion of what climate change education (hereafter CCE) is and how it can be transferred to m-learning platforms for maximum impact. CCE is defined as a set of curricular and extracurricular activities that aim to: 1) providing relevant skills and knowledge for mitigation (e.g. sustainable lifestyles and consumption) and adaptation (e.g. disaster risk reduction and preparedness) in the context of uncertain climate variability; 2) promoting safe, climate-resilient and sustainable learning spaces; 3) engaging the active participation of the community as agents of change; and 4) enhancing interactions between education policy makers and climate researchers (Anderson, 2012). The literature on CCE has grown exponentially in recent years. Drawing on many different disciplines and approaches, it is difficult to distinguish what works from what does not (Galeotti et al., 2024). Despite the fact that CCE is grounded in numerous academic disciplines, due to the multi-sectoral nature of climate change as opposed to its mono-dimensional nature, interdisciplinary research is still more easily planned than implemented. This is primarily due to the strict academic research divisions and insufficient interdisciplinary cooperation across different disciplines and scientific development directions (Kāle, 2024). It can thus be concluded that, in the absence of an overarching framework for the impact, success and long-lasting effects of CCE, approaches, criteria and evaluation metrics must be developed ad hoc on a m-learning project basis.

In the context of evaluating the impact of CCE, single action bias (SAB) emerges as a salient issue. SAB denotes the tendency of individuals to prioritise a single, specific preventive action in addressing climate change, often overlooking potentially more efficacious or comprehensive alternatives (Choudhary and Dutt, 2024). This bias constitutes a substantial obstacle to the implementation of effective climate change mitigation strategies, as individuals tend to emphasise isolated measures, such as energy conservation or recycling, neglecting the systemic changes that are imperative for achieving substantial impact. Despite the pervasive recognition of climate change as a critical global issue, many individuals persist in adopting superficial solutions, frequently prioritising short-term, visible policies such as river clean-up initiatives, while neglecting long-term solutions, including investments in renewable energy research or year-long agro-ecology practices. Exposure to climate disasters has been demonstrated to enhance awareness and promote a more proactive approach, with individuals who have experienced such events allocating greater resources towards climate change mitigation and adaptation (Choudhary and Dutt, 2024).

This chapter underscores the multifaceted challenges inherent in the design of efficacious climate change education curricula delivered through m-learning platforms, emphasising the diverse factors that influence their success. Cognitive biases, particularly the 'single action bias' (SAB), represent a significant impediment, as individuals tend to focus on a single, convenient climate action while overlooking more comprehensive and impactful strategies (Choudhary and Dutt, 2024). The adoption of effective climate change actions is further complicated by social factors, including social norms and observed behaviours. The evaluation framework should include social norms and observed

behaviours, as excluding them may result in the appearance of positive results, as is evidenced by the majority of studies (Galeotti et al., 2024). The farmers of Ghana were able to relate to the training on indigenous crops, which are an integral part of their culture and possess the capacity to demonstrate climate resilience. Moreover, access to infrastructure (i.e. mobile phones) is a pivotal factor in the efficacy of m-learning. Specifically, discrepancies in mobile phone ownership, particularly with regard to gender disparities in SSA, serve to restrict the reach of climate education programmes (Krell et al., 2021). The effective utilisation of mobile learning modules is further complicated by a number of factors, including the timing of m-services, access to appropriate devices, and the decision-making processes of individuals. In order to maximise the impact of m-learning in climate change education, it is essential to consider and address these diverse challenges, including cognitive biases, social dynamics, and access to technology, ensuring that learning platforms are tailored to the needs and realities of all m-learners.

3. Research Design and Methods

The research focuses on an m-learning module aimed at promoting climate-resilient agriculture among smallholder farmers in northern Ghana. The module comprises ten voice messages addressing diverse topics critical for sustainable farming. These include crop diversification for resilience, regenerative farming practices, traditional agricultural wisdom, conservation of indigenous crops, plant selection for seed saving, understanding pollination, harvesting and preserving seeds, reducing pesticide usage, seed sharing within communities, and the benefits of diversifying into indigenous crops. The module content has been developed to address the key challenges faced by farmers, such as climate change, loss of biodiversity and soil health. It also includes a comprehensive introduction to seed saving, covering topics ranging from seed-borne diseases to organic cultivation methods. The module was created in close cooperation with the Latvian partner – the Latvian Permaculture Association, drawing on their extensive expertise in seed-saving practices and sustainable agriculture. The module content was implemented during the 2024, in the period of October-December.

The m-learning module employs Ghana's social enterprise Farmerline's Mergdata platform, which is a scalable mobile and web platform tailored for diverse agricultural stakeholders, including smallholder farmers, outgrowers, agro-input traders/importers, aggregators, regulators, NGOs, farmer groups and more, and it scales from local registries to national reporting. Mergdata's Collect suite allows digital farmer registration, GPS plot mapping, remote data capture via mobile or call centre, real-time farmer profiles and automated reporting. This digital infrastructure supports voice, SMS and USSD messaging, IVR and two-way feedback. It enables inclusive service delivery at scale by bridging knowledge, finance and compliance for agribusinesses, governments, NGOs and farmers alike. The Mergdata platform enables scalable farmer engagement, traceability of produce to its source, compliance with regulations such as EUDR and deforestation, and the construction of data pipelines for business intelligence reporting. The Integrated Suite Mergdata integrates:

1. Terra for land use mapping, deforestation tracking and biodiversity monitoring;
2. Grow for input sales digitisation, order and inventory management;
3. Finance: digital payments, fund distribution and credit profiling.

The application of the Mergdata platform enables farmers to be registered and mapped digitally. It enables direct communication with farmers and provides a platform for payments. The platform also provides compliance-ready traceability, generates custom reports, supports certification audits and equips agribusinesses and their partners with tools for digitising farms and stores. Based on Farmerline's general database, it is estimated that around 89.5% of farmers use feature phones, compared to just 10.4% who use smartphones.

Over 50,000 farmers were identified and targeted by Farmerline's Mergdata platform, delivering content in Dagbani, Konkomba, Buli, Sissale, Chokosi, and English. By integrating voice messaging technology, the project circumvents barriers such as limited internet access and low literacy, providing actionable guidance that complements in-person training programs. The dissemination of this module was strategically scheduled to coincide with key agricultural activities, thereby enabling farmers to immediately implement practices such as intercropping, composting, and indigenous seed conservation. To ensure the localisation of the content, another local partner in Ghana was involved: the Council for Scientific and Industrial Research – Savanna Agricultural Research Institute (CSIR-SARI), which has local and regional agroecology expertise, particularly in the northern areas of Ghana. The m-learning module content was approved for localisation by the Ghanian and Latvian partners together. The number of farmers reached according to languages can be seen in the

Table **1**.

The quantitative evaluation metrics of the m-learning module encompassed reach rates, listening rates, and completion rates, in addition to supplementary measures such as total engagement time and unique listeners as illustrated in the These quantitative insights were supplemented with qualitative feedback from surveys and interviews to assess the relevance, clarity, and practical impact of the messages. It should be noted that baseline study was carried out by Farmerline in close cooperation with CSIR-SARI in 16 district within the Upper East, Northern, and Upper West Region of Ghana due to their long-standing history in production and the right climatic conditions for the production of indigenous crops, reaching 367 respondents answering the questions that provided insights into their demographic profiles, farming practices, market access, and climate change impact on their farms. After the m-learning module implementation, a feedback survey was carried out via phone interviews with 66 farmers from the region, asking their opinion on message accessibility and delivery, content relevance, effectiveness and impact on farming practices, and suggestions for improvement.

Table 2.

Table 1. Language of Voice Message Recipients

Languages	Number of Farmers
Buli	2742

Chokosi	450
Dagbani	34615
Sisaale	7559
Komkomba	3490
English	1942
Grand Total	50799

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Table 2. M-learning Module's Evaluation Metrics

Term	Definition	Significance
Reached Rate	The number of farmers successfully reached with the voice message/ audio lectures as against the target number of farmers	To ascertain the success of the message dissemination for the project and the interest of farmers in the audio lectures
Listening Rate	The proportion of audio content that farmers listen to during training sessions.	Indicates farmers' interest and engagement with the material; a higher rate suggests the content is perceived as valuable.
Completion Rate	The percentage of farmers who finish the entire training module or session.	Reflects the effectiveness of the training in maintaining attention and delivering comprehensible material.
Minutes Spent	The total time farmers spend interacting with the training content.	Serves as a quantitative measure of engagement; more time spent may correlate with better knowledge retention.
Unique Listener	The number of distinct farmers who access the training content at least once.	Measures the program's reach by counting each individual only once, regardless of multiple accesses.

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In addition, 14 real-life workshops were held in northern Ghana, reinforcing the messages of the m-learning module and adding real-life discussions and emotional perspectives (e.g. remembering food consumed in childhood as part of an heirloom heritage). A total of 14 workshops were conducted in all the Northern Regions of Ghana in four districts namely; Gushegu, Savelugu, Saboba, and Yendi. In all, 633 farmers attended the workshops with a gender breakdown of 205 and 428 for females and males respectively. Farmers were trained on three main topics; Diversifying into Indigenous Crops, Seed saving technology, and Regenerative Practices. The training on Diversification into Indigenous Crops focused on the cultivation and benefits of indigenous crops such as sessemi, pigeon pea, and fonio, etc. Farmers explored the nutritional, economic, and climate-resilience advantages of these crops. Also, the training on Regenerative Practices focused on the importance of regenerative agricultural practices and how they enhance soil health, increase crop productivity, and improve sustainability. Feedback from participants indicated a high level of satisfaction with the workshop content and delivery. Many farmers reported a better understanding of the new practices introduced and expressed their intention to implement them in their fields. The workshops also provided a platform for farmers to share their experiences and challenges, fostering a sense of community and collaboration.

From a pedagogical perspective, the intervention adopted a blended learning approach, combining mobile-based instruction with in-person workshops to reinforce key concepts through experiential learning and peer interaction. CSIR-SARI also documented the outcomes in a report, illustrating the use of indigenous local knowledge in northern Ghana and the potential for developing more locally specific m-learning modules for local farmers.

4. Results and Discussion

The implementation of the audio-based m-learning module successfully delivered practical, locally contextualised advice to farmers, with content presented in six languages (Dagbani, Konkomba, Buli, Sissale, Chokosi, and English). These languages were selected based on farmers' preferences as indicated in their profiles on the Mergdata platform, ensuring the accessibility of the content for a diverse audience irrespective of literacy levels. By leveraging voice messages, the module effectively reached over 50,000 farmers across the project regions and beyond, far exceeding the initial target of 10,000 participants. This approach highlights the scalability of mobile-based learning in addressing agricultural challenges. The distribution of farmers across linguistic groups revealed a farming community that was marked by significant heterogeneity. The

Dagbani-speaking group constituted the majority, accounting for approximately 68% of the total recipients, suggesting the presence of a robust agricultural tradition within this community. This demographic observation underscores the necessity of tailoring agricultural extension services to align with the specific requirements and cultural contexts of majority farmer groups, while concurrently ensuring inclusivity for smaller linguistic communities. The variation in group representation may be indicative of historical settlement patterns, cultural farming practices, and geographic factors that have shaped the agricultural landscape over time.

Of the 50,799 farmers to whom the study was administered, 68% were male and 32% female, thus reflecting a significant gender imbalance, the likely influence of which can be attributed to traditional gender roles, societal norms, and the digital divide. It was found that men were the primary recipients of agricultural information due to their dominant roles in decision-making and greater access to mobile technology. Conversely, women encounter barriers such as lower literacy rates and limited ownership of mobile devices, which constrain their participation in extension services. These findings underscore the need for gender-sensitive strategies in future modules, such as explicitly encouraging male recipients to share information with their spouses or developing targeted campaigns to address women's unique needs and constraints.

The voice messages provided farmers with actionable guidance, such as crop diversification strategies, pollination techniques, and natural pest control methods. Overall, as can be seen in 1, majority of lectures' listening rate was comparatively similar for each of the lesson with a preference for practical and immediate advice, such as crop selection for the upcoming season, over general knowledge that was perceived as already familiar. This finding raises important questions about the role of audio messages in either reinforcing existing practices or fostering a culture of sustainability. Timing and content delivery emerged as critical factors for reachability where some lecture – the ones on conserving indigenous grops and seed saving and sharing faced reachability challenges (see Figure 1).

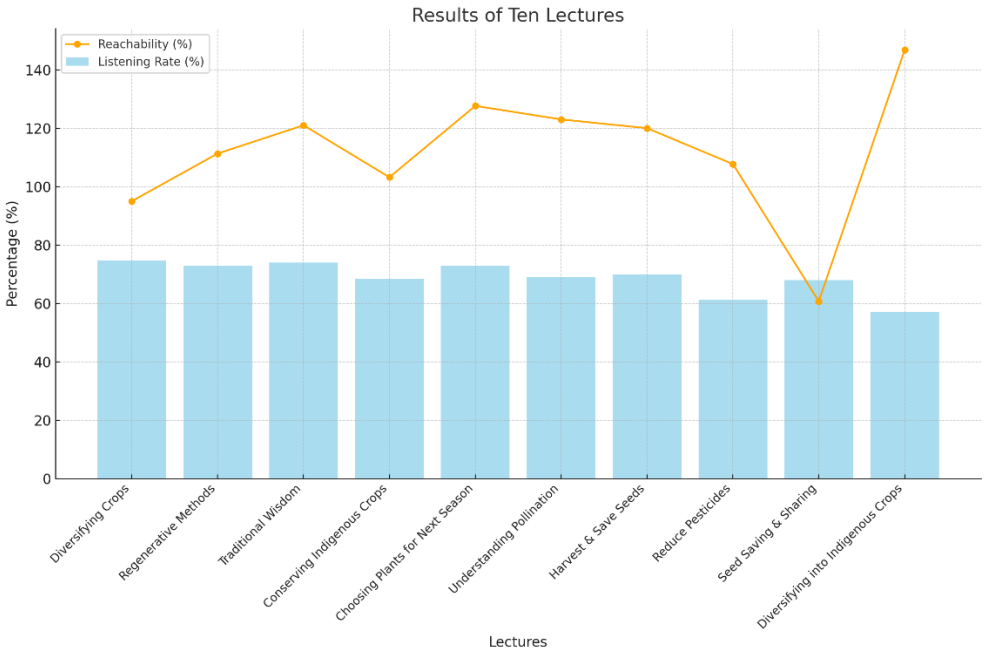

Figure 1: Results of m-learning module of 10 lectures: reachability and listening rate

The findings of this study indicate several domains that may benefit from refinement in subsequent iterations of the m-learning module. Primarily, customising communications to align with the particular requirements and scheduling of agricultural operations can enhance perceived relevance and uptake. Secondly, incorporating emotional and cultural components, such as storytelling and references to community traditions, has the potential to enhance engagement. Finally, addressing gender disparities necessitates a deliberate emphasis on inclusivity, including the promotion of women's access to information and the utilisation of community networks to bridge the digital divide. The findings of this study demonstrate the efficacy of mobile-based learning in effectively reaching diverse farming communities, providing practical and culturally relevant information to enhance agricultural sustainability. However, continuous refinement based on farmer feedback is essential to maximize the impact of such initiatives and ensure equitable access across different demographic groups.

5. Conclusion

This study of the integration of mobile-based learning (m-learning) into agricultural practices in sub-Saharan Africa, particularly in the context of climate change education (CCE), provided important insights into the effectiveness and limitations of these learning platforms. A key finding was the role of relational factors beyond the confines of the nuclear family. Informal and community-based groups provide an essential platform for m-learning, particularly in rural contexts where mobile phones are often shared. These

community networks can bridge the gaps created by income and gender disparities, allowing for more inclusive and widespread dissemination of information. However, this dynamic also presents challenges, particularly when it comes to the complexity of m-learning content. The difficulty of transferring values and norms through mobile platforms is a critical concern, especially when the information involves long-term, abstract benefits, such as climate change mitigation, which are harder to integrate into immediate, everyday agricultural decisions.

An important challenge in utilizing m-learning for sustainable agricultural practices lies in addressing issues related to self-efficacy and the belief in one's ability to effect change. The effectiveness of mobile learning modules depends not only on the accessibility and clarity of the content but also on farmers' confidence that their individual actions contribute to broader collective outcomes. The findings highlight that while m-learning can be a useful tool for delivering information, particularly in remote areas, it is essential to consider how farmers perceive their role in the larger environmental and economic context. Without fostering a sense of efficacy, even the best-intentioned educational efforts may fail to produce meaningful, long-term behavioral change. However, the sense of self-efficacy is superseded by the instinct of survival. Rural communities may be impoverished, yet the key determinate of their behavioural change is hopes for higher incomes in the future.

The study identified gender dynamics and access to technology as pivotal factors in the success of m-learning initiatives. The analysis revealed significant gender disparities, with a higher proportion of male farmers receiving the audio messages. This discrepancy could be attributed to traditional gender roles, cultural norms, and disparities in access to mobile technology. To address this challenge, future m-learning modules should adopt gender-sensitive strategies. This may be achieved by encouraging male farmers to share agricultural information with female farmers, or by designing targeted campaigns that address the unique needs and barriers of female farmers.

In view of the findings, it is evident that the timing and delivery of m-learning content should be adapted to the specific requirements of farmers. For example, messages concerning crop diversification, pest management, or seed saving are more effectively disseminated during key agricultural cycles, such as planting or pre-harvest periods. The emotional aspect of the content also merits further investigation. While the current modules focus on pragmatic, rational information, incorporating an emotional dimension could enhance engagement and foster a deeper connection to sustainability practices. Ultimately, the question of whether m-learning modules should be aimed at long-term goals or more immediate, actionable steps remains open. However, given the cognitive biases and behavioural factors that influence these decisions, future modules may benefit from an approach that focuses on day-to-day decisions that have an immediate impact on farmers' livelihoods and the environment. This gradual approach would build towards more sustainable, long-term practices.

In conclusion, while mobile-based learning holds significant potential for improving agricultural practices and climate resilience, issues of access, gender equality, self-efficacy, and content relevance must be addressed in order to maximize its impact. A key factor in this regard is the economic perspective, since farmers are more likely to engage with m-learning platforms when they see direct financial benefits, such as increased income from better yields or improved market access. Therefore, long-term behavioural outcomes could best be documented through more diverse farm output offerings in markets and a higher profit margin for farmers. By tailoring content to

emphasise both sustainability and economic gains, m-learning can better align with the immediate needs and long-term goals of rural farming communities, fostering greater participation in climate resilience efforts and empowering farmers to make informed, economically beneficial decisions.

Acknowledgments

This research is funded by the "Building Digital Education of Indigenous/Heritage Crops for the Resilience of African Food Systems in the Climate Crisis" (ICRAFS) project, which is supported by the Development Cooperation Budget of the Ministry of Foreign Affairs of the Republic of Latvia for 2024-2025 LATDEV. However, the Ministry of Foreign Affairs of the Republic of Latvia does not take any responsibility for the content produced within the project.

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Received February 19, 2025, revised July 4, 2025, accepted September 9, 2025